Augmented Vision in a Degraded Visual Environment for Aircraft Landing Operations

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***Abstract*—Inclement weather conditions such as fog and clouds can obscure pilots views of the runway during landings. As a solution to the problem of landing airplanes under such poor visibility we propose a real time method of using multi-sensor fusion to create an augmented view of a runway on a heads-up-display (HUD). The use of such a method in a HUD would give a pilot the assistance to land without turning their head from the windshield during landings and reduces risk of loss of property and life.**

***Index Terms*—Augmented reality, synthetic vision, sensor fusion, aviation, pilot**

I. Introduction

The application of autonomy in aircraft has expanded over the past few decades, providing various safety functions and flight augmentation systems through to full mission profile control. As the presence of autonomy continues to increase in aircraft applications, it is important to ensure that a human pilot present in the cockpit in semi-autonomous control has the necessary information available to ensure that the autonomy functions are performing as intended. One area where this is particularly important is in close proximity to the ground such as in the landing phase.

There have been different ideas proposed around runway tracking for auto-land systems, between using ILS based approaches and GPS based approaches, to vision systems for tracking the runway edges and centerline. While each of these methods can provide a reference to an autonomous system for performing a landing, there are also drawbacks. For example, many smaller airports do not have ILS approach capabilities, meaning that aircraft can only operate out of those airports with visual flight rule (VFR) conditions. In the case of GPS there are concerns about the robustness and accuracy of using strictly lat/long based data when there is only an allowable margin of error on the order of 10s of feet. Finally, for vision based systems this requires that the camera systems have a line of sight to the runway environment with no obstruction.

In the semi-autonomous case where there is a human pilot present in the cockpit monitoring the performance of the autonomous functions, it is important to provide performance information to the pilot in a clear and understandable manner. One example for providing information in a central location is through the use of a Heads Up Display (HUD). The use of a HUD in aircraft provides the pilot with a quick reference of key information such as heading, altitude, vertical speed, and airspeed while allowing their attention to remain outside the cockpit. This is particularly important when the pilot needs to perform detect and avoid maneuvers that the autonomy functions might not be equipped to handle. Another area where the HUD could be further utilized is in the previously mentioned autoland case.

This paper will present a method of fusing sensor information to improve the robustness of auto-land systems while providing a visual reference to the monitoring pilot through a HUD. The HUD will provide an overlay reference of the relative location of the runway such that it will be easily recognizable if the aircraft is deviating in a manner that is unacceptable for this critical phase of flight. In addition, this overlay will continue to be provided when the runway itself is obstructed from view such as during instrument approaches to provide further situational awareness.

II. Literature Review

The goal of this paper is to provide a synthetic vision system to a pilot in a semi-autonomous aircraft. As described in Enhanced Vision System Option on Future Aircraft by Paul Leckman in [1] a synthetic vision system in aircraft can improve the availability of airport operations such as expanding operations in poor weather, it can reduce the chance of runway incursions, and it can provide improved situational awareness to the pilot. As this paper was published in 1991, we have seen some of these technologies come to the market, and sensors have improved over the last 30 years, thus many of the proposed considerations from this paper are possible with today's technology. In particular, this paper mentions the use of different forms of GPS, RADAR, and LiDAR sensors which can be fused to provide terrain and obstacle detection, low visibility situational awareness, and weather awareness. In addition, the paper mentions the use of aircraft state data to improve the robustness of the vision systems. Finally, the paper mentioned the standardization of HUD symbology for ease of use for pilots. Each of the elements in the paper will be further considered for application to the proposed method in this paper for providing a synthetic vision system.

A system for fusing vision with inertial information of an aircraft for robust runway detection was proposed in 2018 by Khaled Abu-Jbara et al in [2]. This paper looked at the use of vision based runway detection systems combined with inertial information from the aircraft to improve the robustness of runway tracking for unmanned aerial vehicle (UAV) landing applications. This paper provides a good basis for vision tracking systems, however as mentioned previously, this system does not work in the case where the runway is obstructed form the UAVs view, allowing operations only in VFR conditions.

In Human-machine Collaboration through Vehicle Head Up Display Interface by Charissis et al in [3], they propose a camera and radar based system that provides information on a heads up display to outline the location of other vehicles in a low visibility driving environment. The particular focus of this paper is on the symbology and interface of the HUD to ensure that information is provided in a clear, non-distracting manner to the driver which will be used as a reference for this paper, as the vision system is not applicable to an aircraft due to sensor range limitations.

Another method to identify airport runways is achieved by matching data to a known universe of runways as described by [4]. The authors mainly used infrared and visible range videos in clear, foggy and rainy conditions through day and night as their test data-set. A high detection specificity, correctly identifying the approached runway and rejecting the other runways was observed in all conditions. Although for the visible range of videos, runway identification repeatability was observed only during day time (compared to nighttime). The algorithm works in several steps starting from selecting way points and referencing images, image matching and finally determining way point-based location using statistical ensembles of video frames. The authors found certain repeatability across visible and shortwave sensor bands. Finally the authors also compared camera-based geo-location during aircraft landing to the standard visual approach Procedure.

There are several reasons a HUD is useful for pilots while navigating in degraded visual environments. The usefulness of an indication of instantaneous inertial flight-path was demonstrated by [5]. The authors relied on the Ames Flight Simulator for Advanced Aircraft (FSAA), to conduct their experiments. The paper talks about how the HUD is fully used by the pilot in several different conditions and landing approaches. Their results showed that pilots accepted a ”new” heads up display with certain ease. The rapidity of acceptance of most of these unfamiliar forms of the HUD is considered a measure of their effectiveness. This shows that novel HUDs that communicate effective information are generally well accepted by the pilots. Our aim is to develop a HUD that will enhance the pilots capabilities to land even in degraded visual conditions.

III. Materials and Methods

This work aims to devise an algorithm to provide a real time view of an airport runway during the landing operation under degraded visual conditions. Visual conditions such as heavy rain, fog and cloud, poor illumination, and other means of obstructing the runway view during landing will be considered by this work.

Aircraft data and imagery is simulated using the 3rd party software, X-Plane. The software provides realistic flight simulation in a variety of environments and locations. Flights were performed in the simulator and recorded at a rate of 30 frames per second. The video from X-Plane was then processed thru Matlab specifically by converting the images into frames and gray-scale images for further processing. Results will be rendered back through the X-Plane simulation using their synthetic imagery tools [6].

Fig. 1: Degraded View of Runway During Landing

Fig. 2: Augmented Runway View

The flight simulator is capable of providing all manner of data on the state of the aircraft and environment throughout the flight. Data such as velocity, acceleration, altitude, location, as well as heading, pitch and roll. The data and the video or taken separately and require further processing to correlate the data to the image frames.

We will develop our algorithm using MATLAB and specifically the MATLAB Sensor Fusion and Tracking Toolbox which has a great IMU model that can be integrated with INS/GPS data [7].

To begin, the method from [2] was adapted to create a baseline function for runway detection and tracking with visual frames from a video feed of the X-Plane simulation. From

Fig. 3: Flight Simulator Runway View

there, the algorithm was expanded to a sensor fusion model that includes additional aircraft state sensors. The sensors include aircraft inertial state information, GPS, and cameras which will form the inputs to the algorithm. In addition to aircraft odometry and visual sensors, the method will also include a database of airport runway information.

The runway detection algorithm began by extracting a frame from the video provided by X-Plane, and a canny edge detector was applied in order to extract the edges which could be associated with the runway edges and centerline. The canny edge detector uses the derivative of the Gaussian filter. The Matlab method in particular uses two thresholds which reduce the erroneous influence of noise in the detecting edges [8]. The threshold of the canny detector was set to capture lines that were potentially runway edges while ignoring fine edges that were not useful to our runway search.

This edge image was then used with the Hough Transform to detect the presence of lines. These lines would provide a smaller dataset with which the runway itself could be identified. The Hough Transform takes in the edge image as a set of individual datapoints, and each of these edge points then produces a cosine curve in the Hough space, and the number of intersections of the cosine curves at a set ρ and θ pair can indicate the presence of a line in the image. The threshold for the number of intersections necessary to detect a line is an adjustable value.

In addition to the detection of the runway via the camera, we also developed a method for estimating the position of the runway using GPS and aircraft inertial data. This method begins by obtaining the aircraft's current GPS location and creates a world coordinate system that then provides the runway location relative to the location of the aircraft. Then, using the orientation information of the aircraft, a rotation matrix is then applied to align the coordinate system with the nose of the aircraft. The points that correlate with the start of the runway are then projected onto this coordinate system to create an "image" of the GPS estimated location of the runway as the pilot might see it from the cockpit. This GPS image estimation is useful for providing a coarse estimation of what the pilot might see from the cockpit, however it does not require that the runway is visible to the aircraft's camera, meaning that it would be operable in poor visibility and weather conditions. In addition, this estimation can improve the efficiency of the camera based runway detection method by refining the area of the image which may contain the runway edges, helping to eliminate false edge correlations when the runway is visible to the aircraft. Ultimately, due to a lack of camera information this method did not prove fruitful, which is discussed further in the results.

The next step was the generation of the HUD. The HUD was oriented in the coordinate frame of the nose of the aircraft, and the objective of the HUD was to project the runway even when occluded from the frame of reference of the aircraft nose. In a clear environment, using the visual data (image) from X-Plane, the runway is detected through the canny edge detector and Hough transform noted prior and projected onto the image. These steps provided promising results but there were a lot of anomalies detected as well as the lines that detected the edge of the runway were often disjointed/intermittent as shown in Fig 7. To improve this performance, only the lines that were within a certain angular threshold of the vertical axis were chosen, the rest were eliminated. To tackle the issue of disjointed lines, after the Hough transform has found the lines in the image and after the outliers are removed, all the lines with the intercept and slope within a threshold are bundled together and plotted as one. This leads to a cleaner runway projection as shown in Fig 8.

IV. Results

Flight imagery was captured using X-Plane. Video was converted to individual image frames and only every tenth frame was used to improve processing times. The simulated weather during the flight reduced the visibility of the runway to what would be dangerous levels for real world flight. A clear view of the runway is shown in Figure 4. The runway obscured by fog is shown in 5. Canny edge detection was performed on the images. Through canny detector parameterization an image with an acceptable amount of edges was produced. The resultant image is shown in Figure 6. These images were then processed using the Hough transform function on Matlab, to identify lines from the edges. These lines were highlighted and overlain on the original image, as shown in Figure 7. Finally the Hough lines were reduced and smoothed to the HUD output shown in cleanRunway.

Fig. 4: Standard Image from Flight

Unfortunately, the GPS based method was not able to be fully tested due to a few limitations. These limitations include a lack of information on the camera used by X-Plane, so

Fig. 5: Image from Flight with Degraded View

Fig. 6: Canny Edge Detection

Fig. 7: Hough Transform

matching the image window generated with the GPS based runway points and the image window provided by the X-Plane simulation proved impossible within the limits of this project. In addition, since the X-Plane simulation was not directly interacting with the Matlab code, it was difficult to align the image frames from the recorded video of the simulation with the data output from the simulation. This meant that we were unable to verify that the projection of points from GPS and orientation data aligned with the correct points in an image from the video feed. Figure 9 shows an example of the desired output from the GPS estimation method where the three points in the image align with the left corner, centerline, and right corner of the end of the runway as seen from the cockpit of

Fig. 8: Runway Lines Detected

the aircraft, with the aircraft looking straight down the runway at an altitude of 1000 ft.

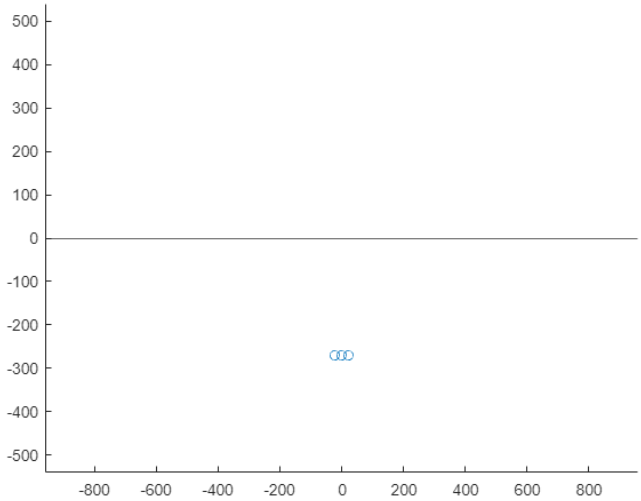

Fig. 9: GPS Estimation of Runway Endpoints

V. Conclusion

This paper presented a method for detecting runways in non-adverse conditions. Runways could then be highlighted on a HUD as an aid to the pilot during landing operations. The paper further aimed to highlight the runway in degraded visual environments. While a method was devised and considered to complete the goal of projecting the runway in poor visual environments, it was not successful due to aforementioned limitations.

VI. Discussion

Recommendations for future work on this project include linking the Matlab code with X-Plane directly such that the runway detection could be implemented in real time with the simulated flight. In addition, further clarification of a GPS based approach would be needed to ensure that the runway could still be approximated in entirely obstructed visual environments. The GPS approach could then also be combined with the visual information in order to improve

the robustness of the runway detection in cluttered visual environments.

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